

A 21st Century Approach to Reliability

Electrical Engineering

Mark Law, Aristotle, Ebers, Fellow

Toshi Nishida

Scott Thompson, SEMI Technology, Fellow

Gijs Bosman

Materials Science

Steve Pearton – Ebers, Bardeen, Fellow

Cammy Abernathy - Fellow

Brent Gila

Kevin Jones - Fellow

Chemical Engineering

Fan Ren - Fellow

Post-Docs

Michelle Griglione, Erin Patrick

Nick Rudawski, Chih-Yang Chang

Students

Erica Douglas, David Cheney

Amit Gupta, Andy Koehler

Nicole Rowsey, David Horton

Hemant Rao, Ray Holzworth

Patrick Whiting, Min Chu

Danny Zeenberg, Weikai Xu

Liu Lu, Tseng Sheng Kang

Chien Fong Lo, Xiaotie Wang



Agenda and Logistics – Nov. 10

- 8:15 AFOSR Program Manager, Jim Hwang – Perspectives
- 8:30 Reliability MURI Contributions to Industrial Reliability Efforts, Kurt Smith, Raytheon
- 9:00 MURI Overview (Mark Law)
- 9:30 Effect of electrical stress on GaN HEMTs - Douglas
- 10:20 Break
- 10:40 Electrical Characterization
 - Overview – Nishida / Bosman (15min)
 - Effect of Mechanical Stress on Gate Current and Degradation– Nishida & Thompson Students (50min)
 - Gate stack reliability in GaN HEMTs using low frequency noise measurements Xu (20min)
- 12:05 Lunch – Buffet Style + Posters
- 1:15 Materials Characterization
 - Overview – Jones / Gila (15min)
 - SEM + TEM Prep LEAP Atom Probe – Jones' Students (35 min)
 - Trap States in Electrically Stressed HEMT's – Cheney (20 min)
- 2:25 Break
- 2:45 Simulation
 - Overview – Law (15min)
 - Calibration of ElectroThermal Simulations – Contact Resistance Griglione 1(5min)
 - Electro-thermal-mechanical Convergence Issues – Patrick (15min)
 - Degradation in Insulator due to Radiation – Rowsey (15min)
 - Electromechanical Degradation and the role of interfacial oxide – Horton (15min)
- 4:00 Wrap Up, Caucus, Feedback

Presentations at:
www.reliability.ece.ufl.edu

Precompetitive Engineering Scientific Research Focus

- Scientific Understanding of Materials Properties
- Understanding of Electrical Signatures
- Modeling / Simulation of Failure

- Black' s Equation Empirically Captured Aluminum Electromigration in 1969
- Subsequent work on
 - Characterization of field, current density, temperature dependence
 - Characterization of mechanical stress
 - Characterization of grain size diffusion along grain boundaries
 - Characterization of etch effects related to grain size
 - Full 3-Dimensional Grain Models

Recent Papers in 2008 and 2009 - 40 years of science based pubs

Scientific Issues and Importance

Inability to model and predict electronic device failure modes from first principles and underpinning physical mechanisms

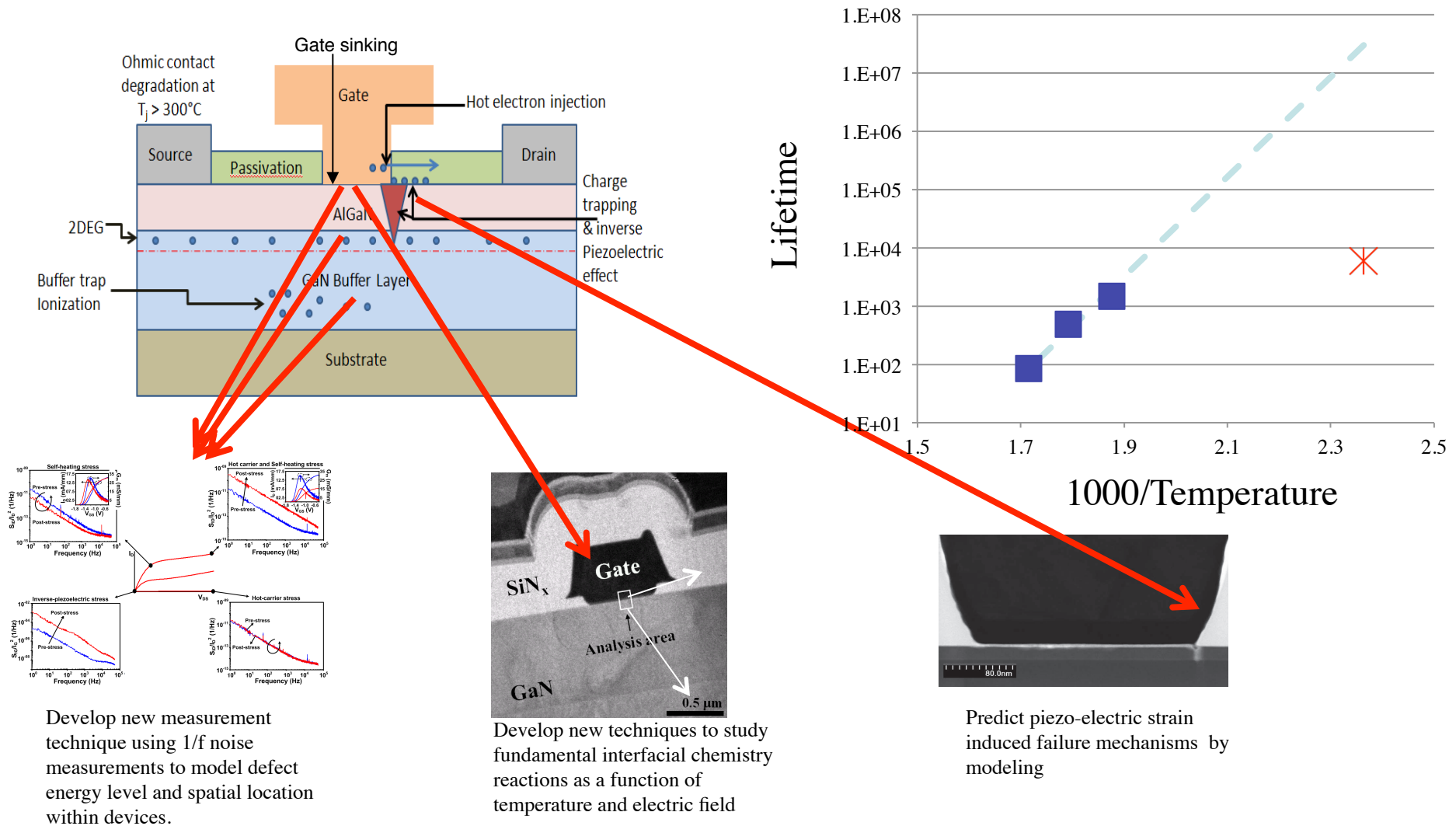
Challenges/ Expected Breakthroughs:

- Lifetime prediction for compound semiconductor device operation is difficult because of poor underlying models
- Elevated temperature testing fails if degradation is driven by field, mechanical stress, hot carriers
- Elevated temperature testing fails if degradation is masked by another mechanism with higher activation energy

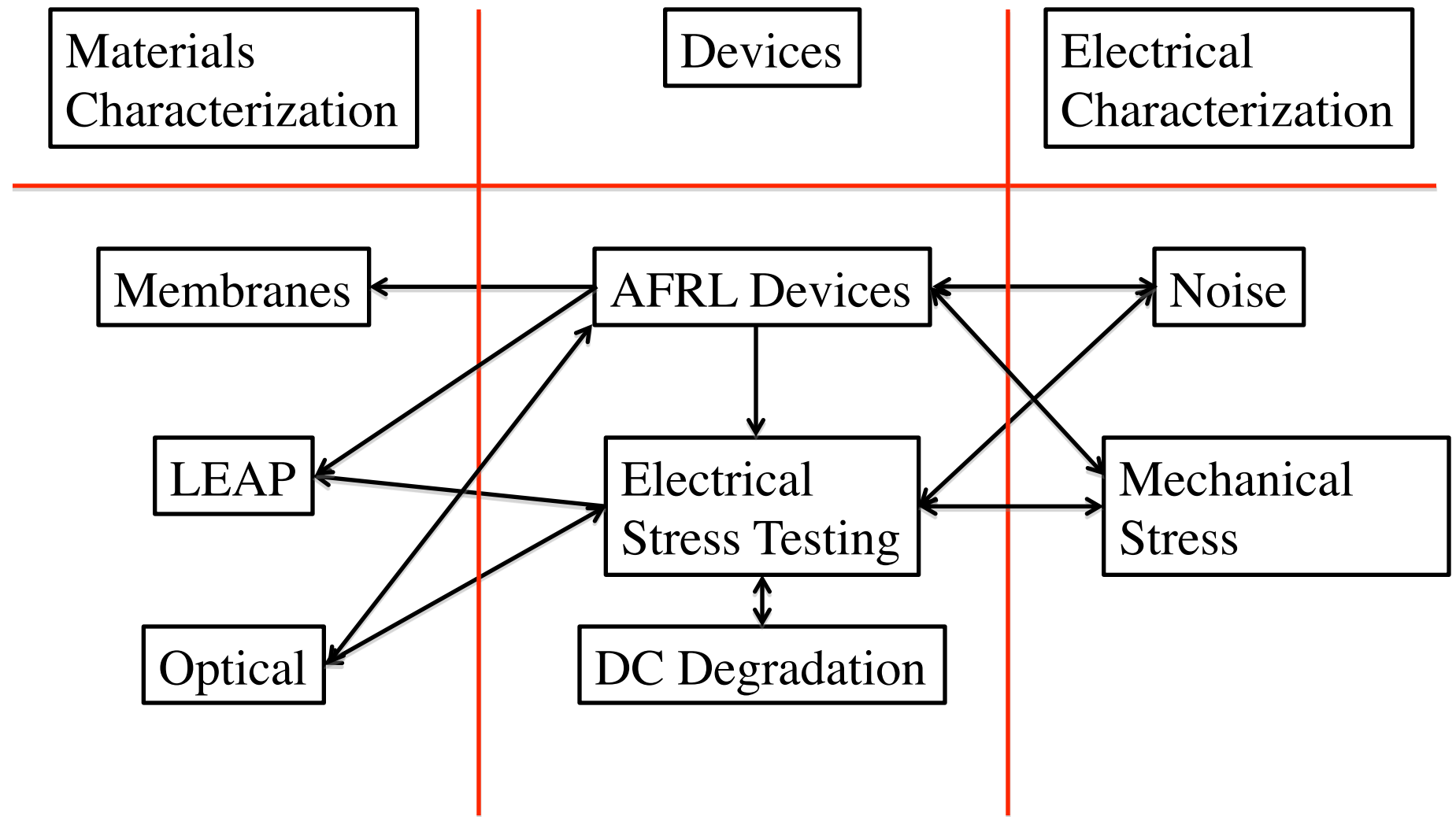
Develop new physical modeling capabilities and tools

- Accurately keep pace with new material systems
- Changes in operating conditions
- Combining physical models, chemistry, materials science, electrical engineering to develop understanding

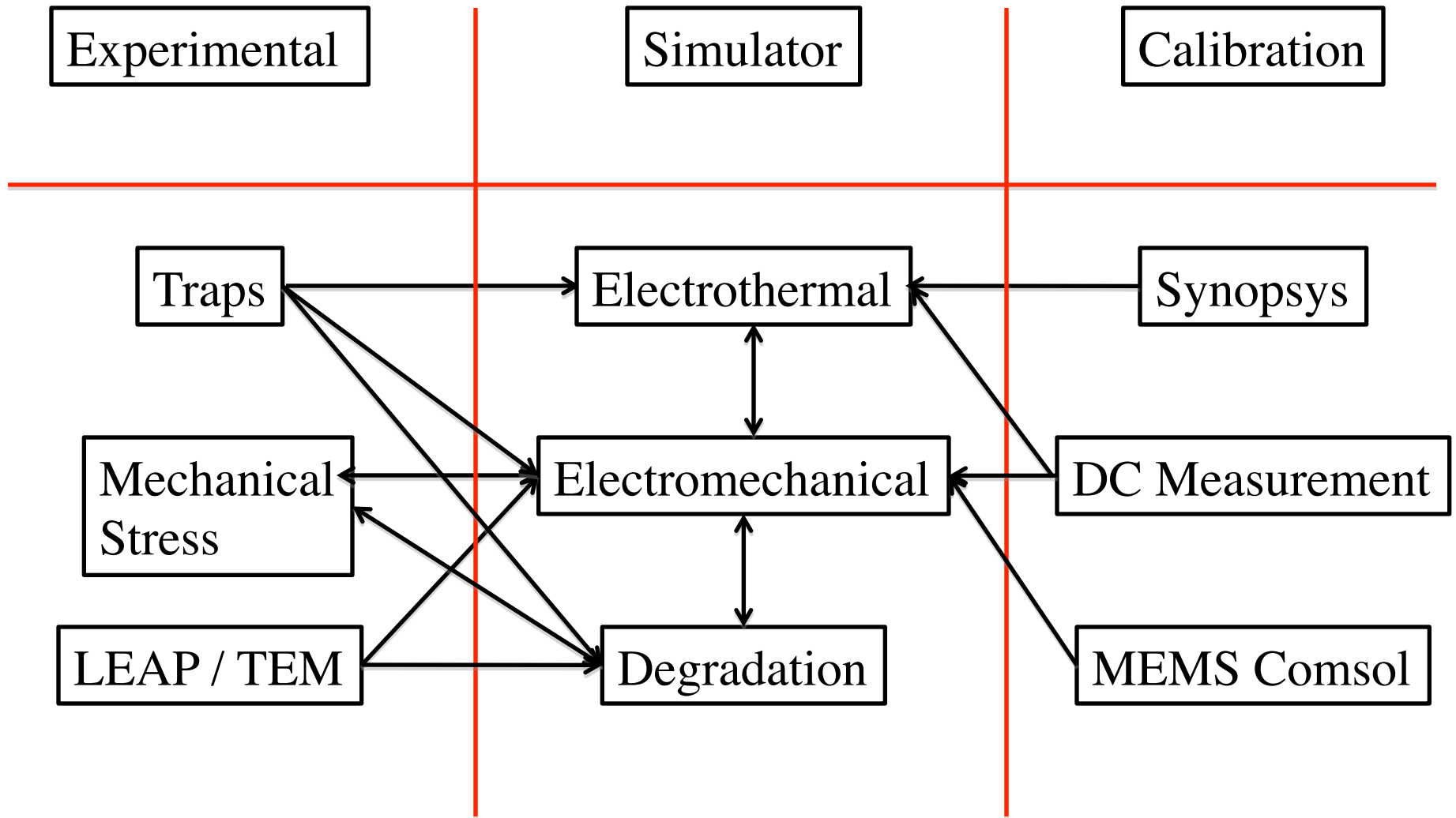
Understanding Device Degradation Physics



Device and Material Flow

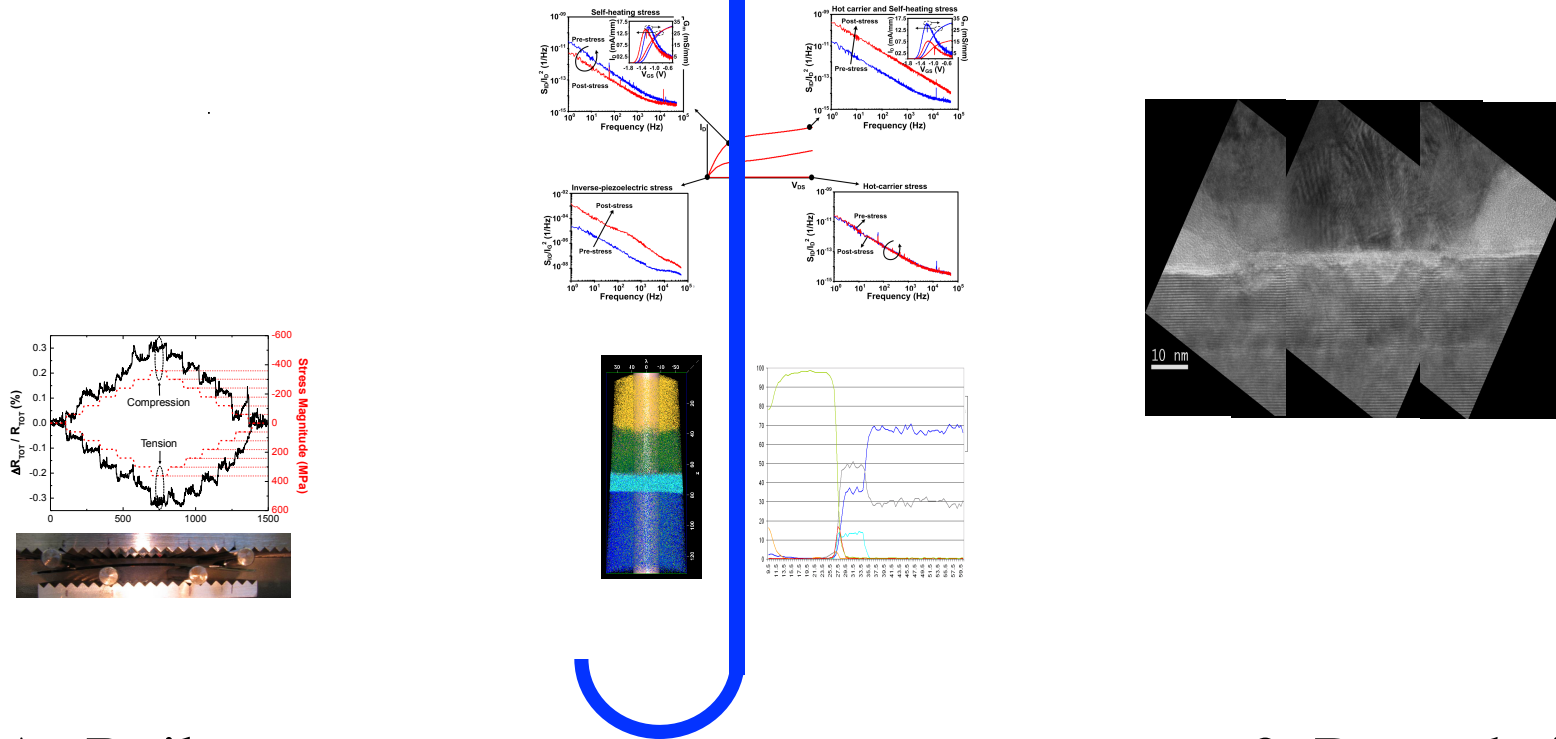


Theory Flow



Scientific Approach

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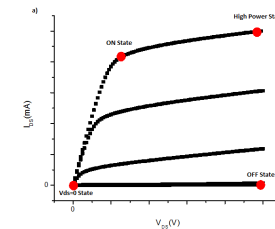
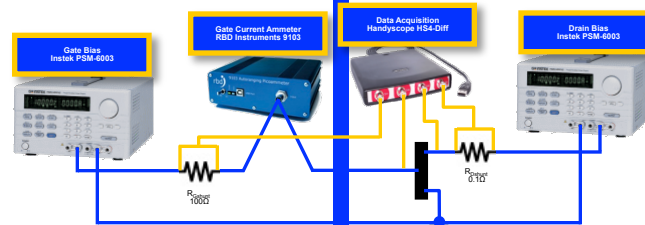
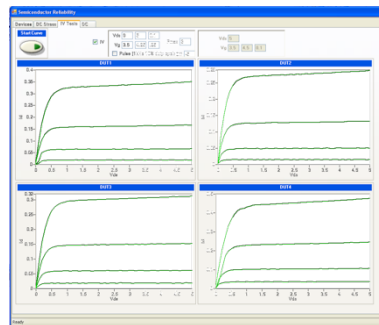
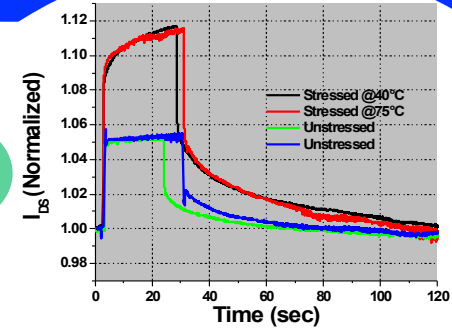
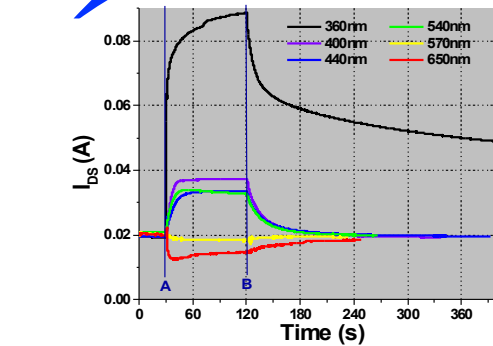


$t=0$, As Built

$t>0$, Degradation

Reliability Test Station

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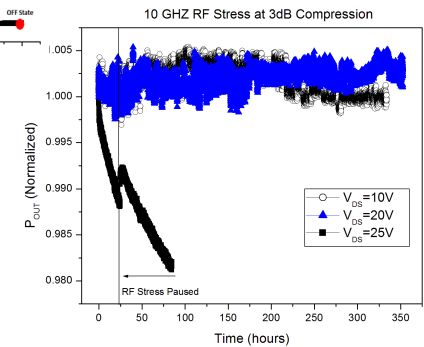
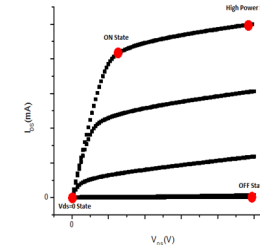
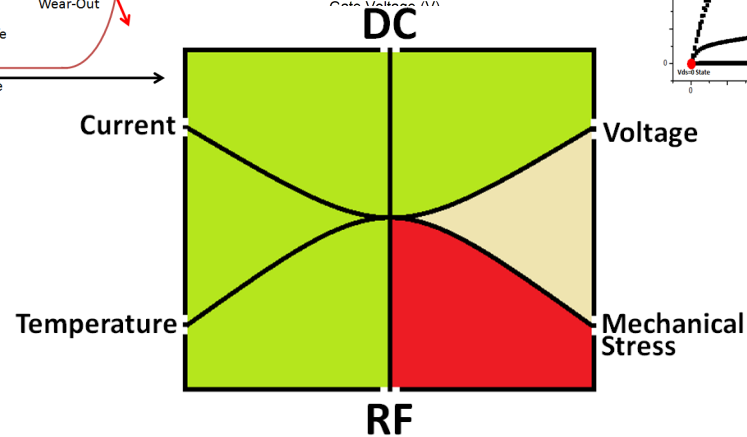
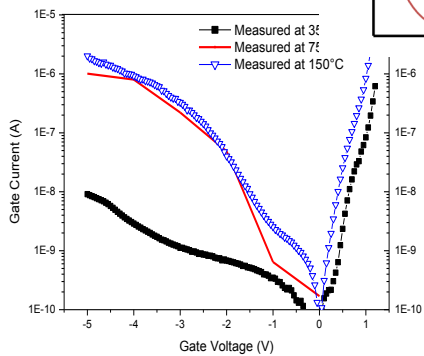
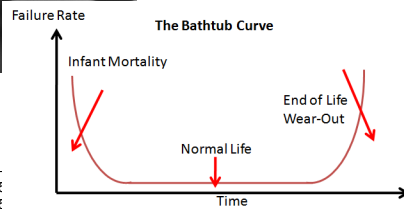
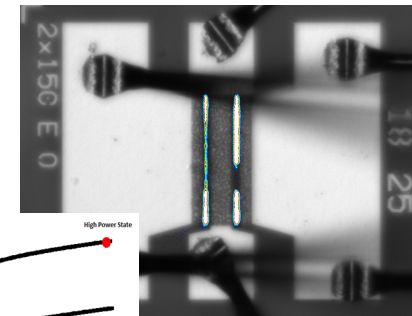
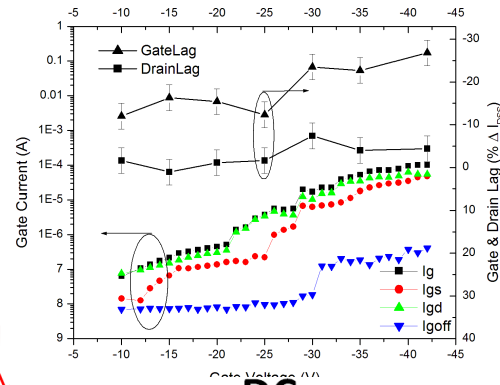
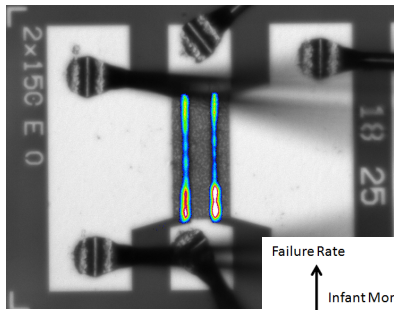


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$t>0$, Degradation

Device Degradation Under Test

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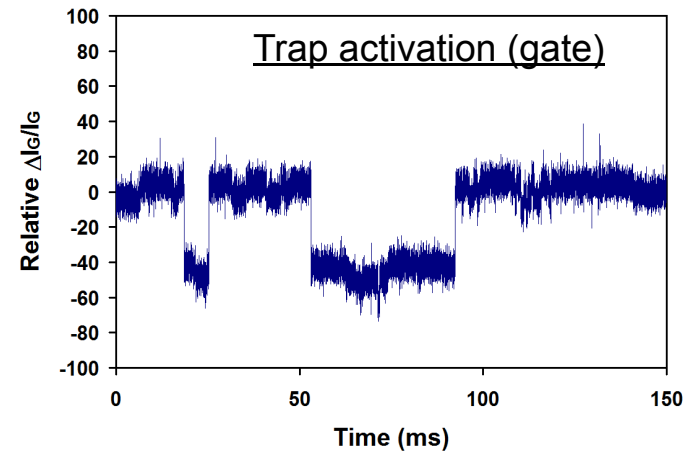
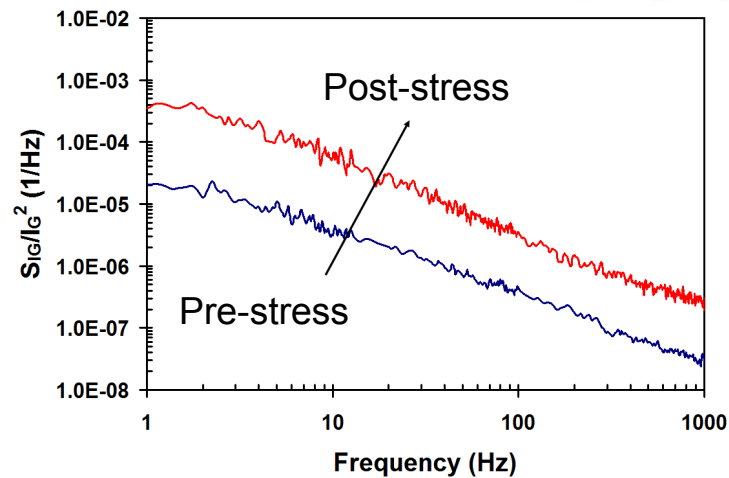
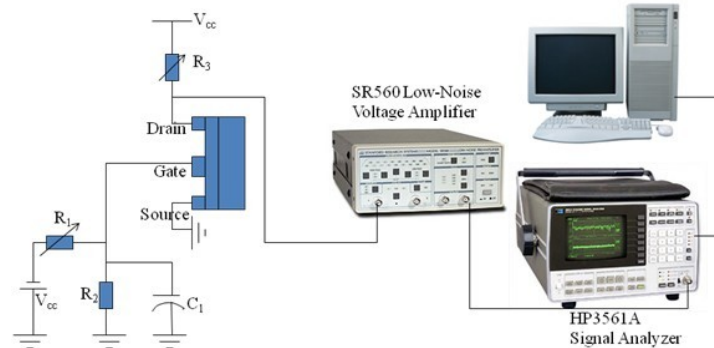


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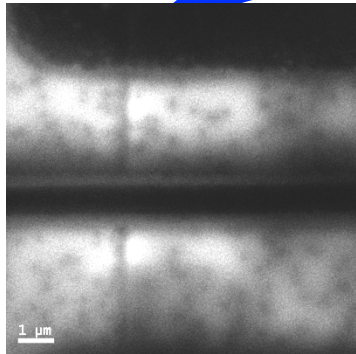
Trap Characterization

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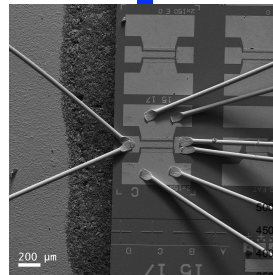


CL and PL Characterization

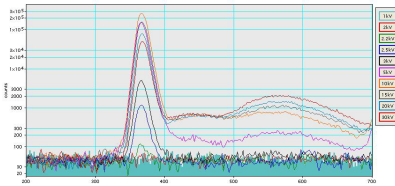
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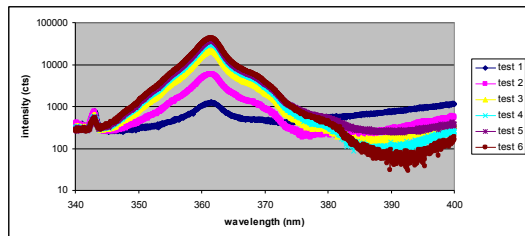
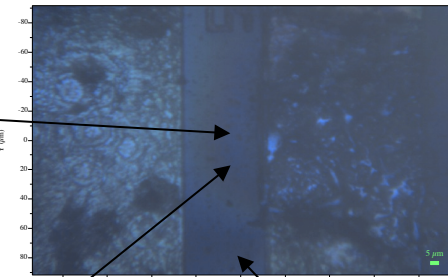
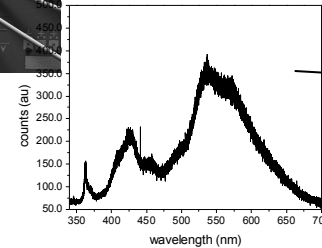
CL on pre stressed device



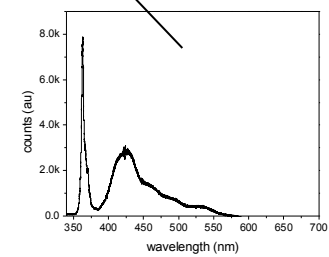
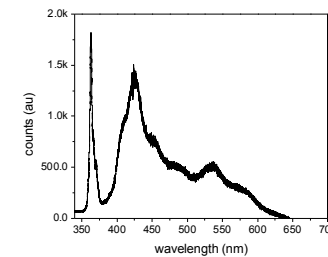
PL on post stressed devices



CL depth profiling



PL on bulk epi and pre stressed devices



$t=0$, As Built

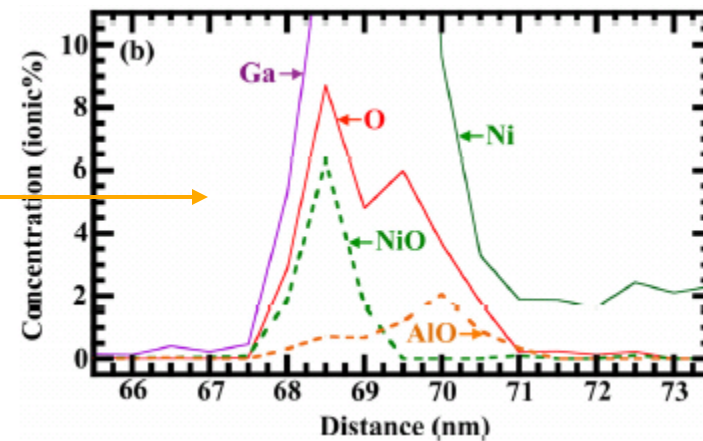
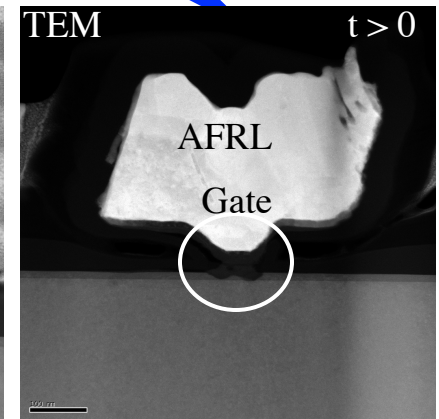
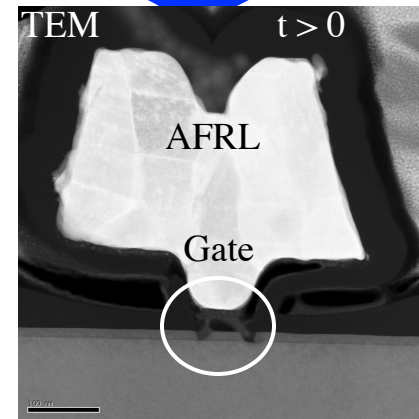
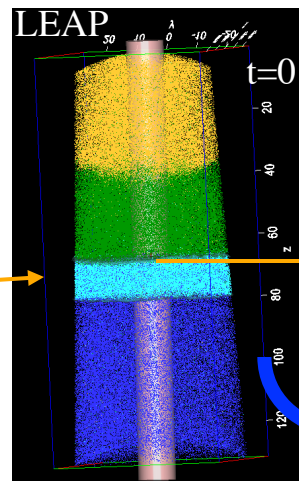
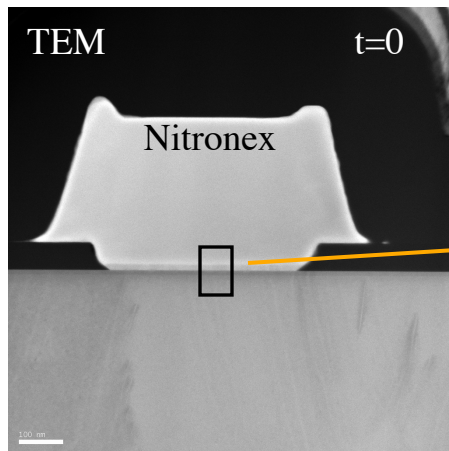
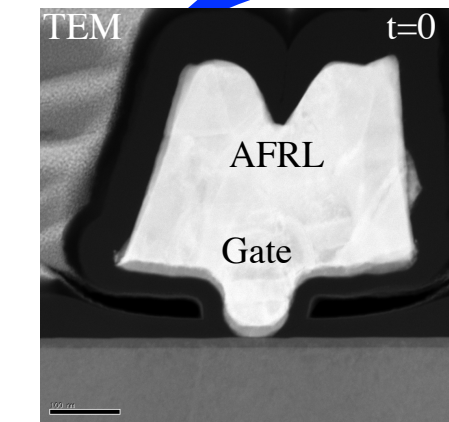
$t>0$, Degradation

Materials Characterization

$t=0$, As Built

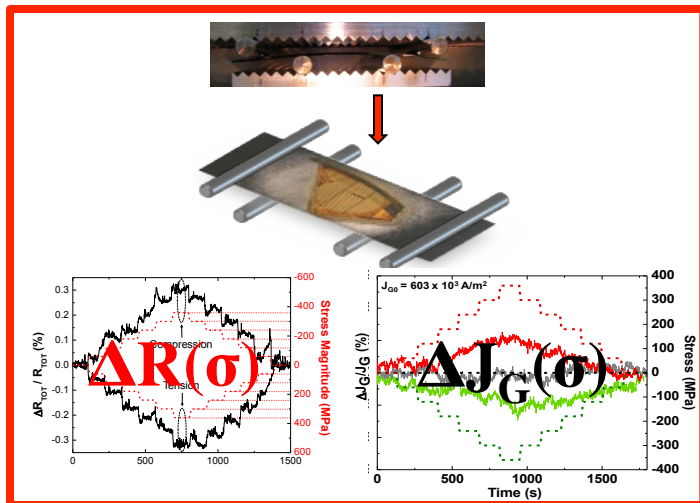
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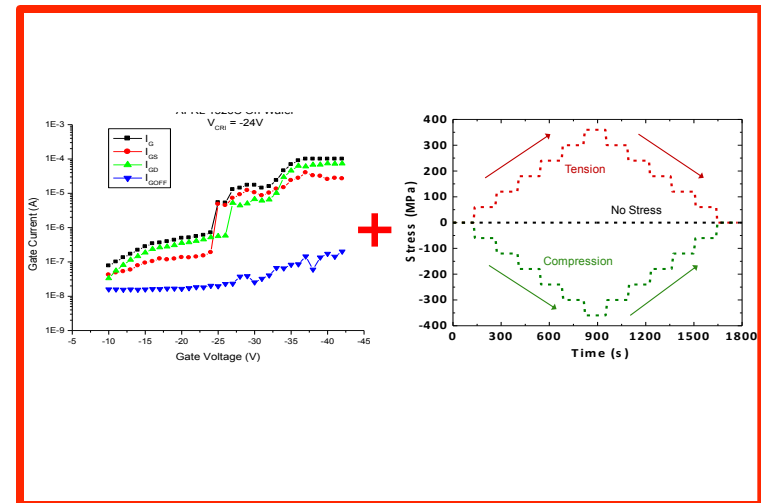


Mechanical Stress

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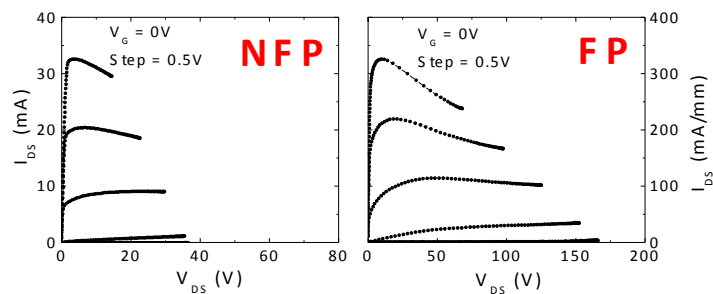
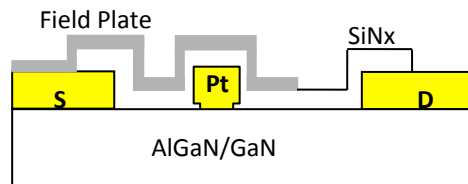
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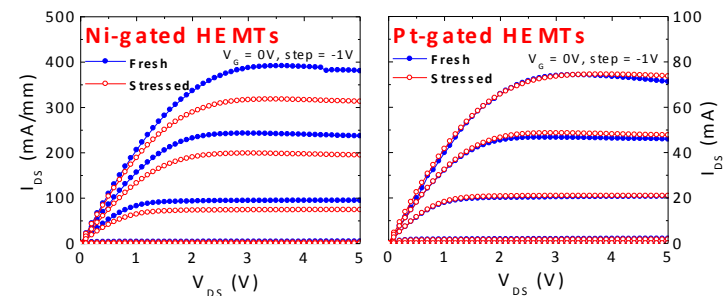
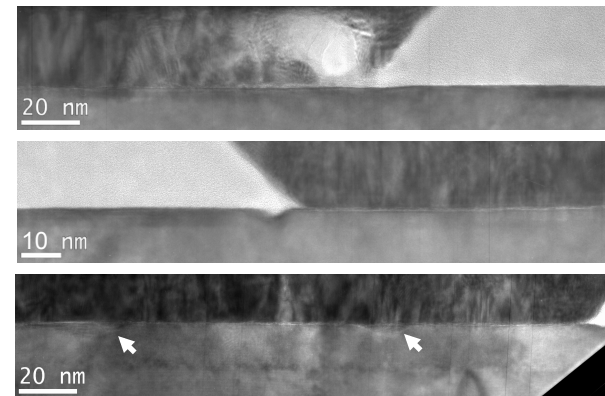
t>0, Degradation

Reliability Testing

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$t=0$, As Built



$t>0$, Degradation

Simulation

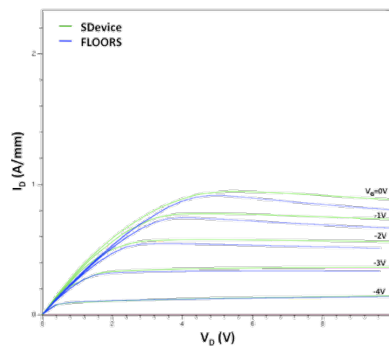
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$$H = -\nabla \cdot (P_n T + \phi_n) J_n - (E_C + \frac{3}{2} kT) \nabla \cdot J_n$$

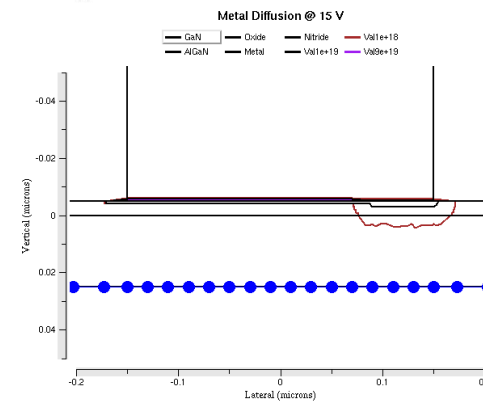
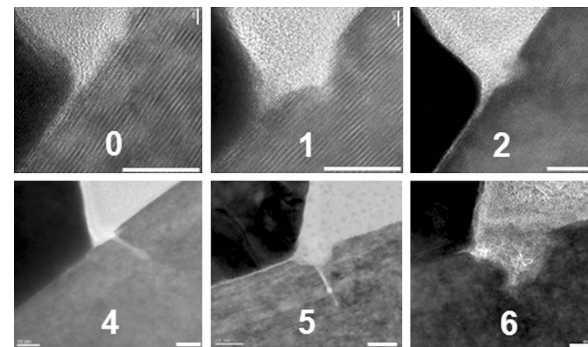
Heat Generation Model Refinement

S/D Resistance Development

Carrier Ionization Development



Model & Simulation Calibration

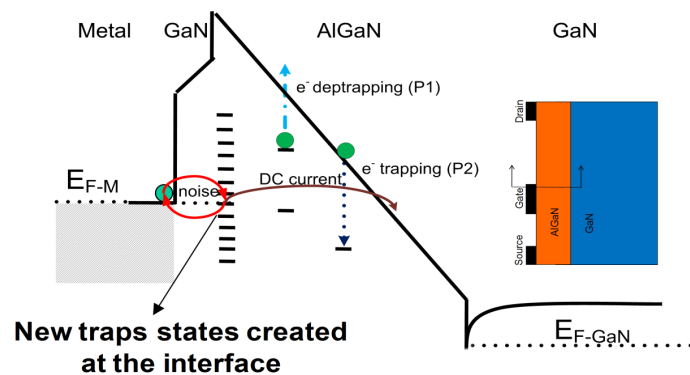


Electrothermal Simulation

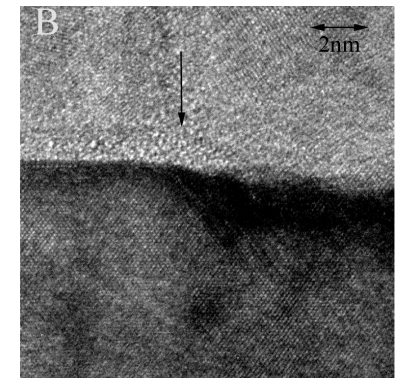
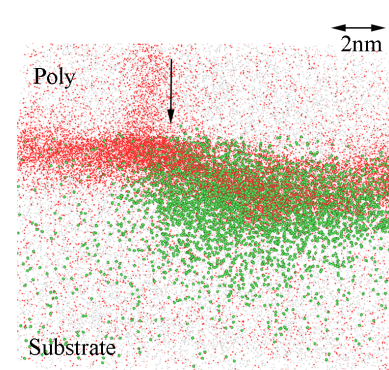
Future Directions

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Integrated Electrical, Thermal, Mechanical Simulation



Defect Location and Generation
Driven by Field, Mechanics, Thermal



Material Reaction / Interdiffusion
Driven by Field, Mechanics, Thermal

Unify previous techniques and combine with FLOORS to gain
and applicability of physics of failure.